II

SCENERY OF THE ATLANTIC SHORELINE[1]

INTRODUCTION

THE margins of the continents exhibit scenic features which have not always received the consideration they deserve, although no other type of landscape is more full of significance. The shoreline registers those great changes in the relative level of land and sea which are of prime importance in the history of continents and ocean basins; and shoreline scenery thus tells a fascinating story of past events which cannot fail to interest everyone who understands the language spoken by cliff and beach, marsh and bay.

It is my intention to consider, very briefly, the force which is mainly responsible for shoreline changes, namely, the waves; then to describe characteristic scenic features of the two great types of shorelines which border most of the continents, North America included; and finally to show how the shoreline scenery of the eastern coast of North America answers the question: Is that coast gradually sinking into the sea?

WAVE ACTION

First, let us examine the force which carves the sea-cliffs, builds the beaches, throws up the offshore bars, and ultimately eats its way into the continents. Driven by the wind, the water particles swing in circular orbits in such manner that when they rise to the top of the orbit they form the

[1]Public lecture delivered at the Rice Institute, March 14, 1934, by Douglas Johnson, Ph.D., D.Sc., Professor of Physiography in Columbia University.

crest of a wave; and when they descend to the bottom, the trough of the wave is formed. Where the sea is shallow and there is not enough water to make the whole body of an ordinary wave, we often see the hollow shell of what is commonly called a "combing wave" (Fig. 1).

It is true, of course, that the maximum erosive work is accomplished not by graceful small waves like that shown in Figure 1, but by the larger storm waves which attack the lands with resistless fury (Fig. 2). Measurements of the force of such waves show that they strike vertical cliffs with a pressure as high as six thousand pounds per square foot. Neither the works of man nor the creations of nature can withstand such force. The accompanying illustrations (Figs. 3–6) show four views of the same house on the coast of New Jersey, built on what was believed to be a reasonably safe part of the shore, and protected against possible inroads of the sea by a solid wall, with a line of pilings some distance out to break the impact of the waves. In the first

FIGURE 1. Combing wave.

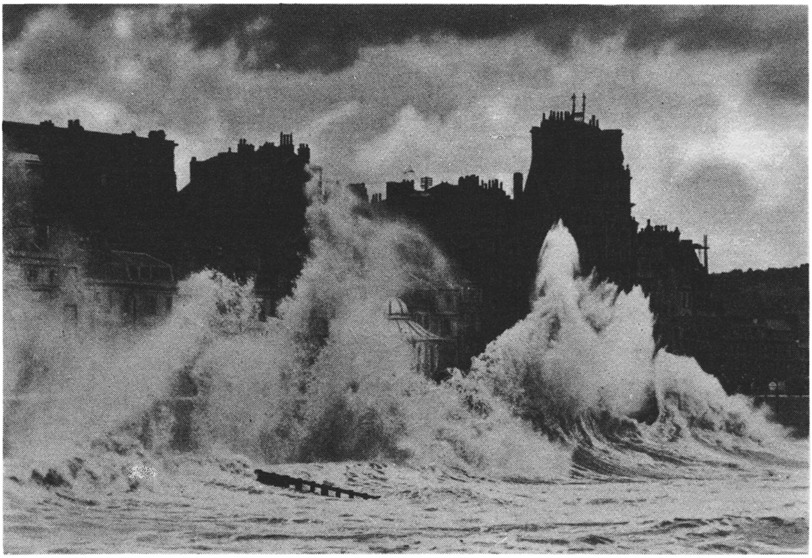

FIGURE 2. Storm waves at Hastings, England.
Photo by Judges.

picture (Fig. 3), the waves are shown partly decomposed at the line of pilings, but strike the seawall with sufficient force to throw water high in the air; the house is still safe. In the second view (Fig. 4), the waves have broken through the seawall at one point, and are beginning to undermine one corner of the building; while the fury with which they are attacking the remaining part of the seawall threatens its early destruction. A third stage (Fig. 5) shows that the seawall defenses are effectively breached, and the earth cut away from under the larger part of the house. There remains but one more stage in the disintegration of this attractive summer home under the attack of the sea; and this is shown in the fourth view (Fig. 6). The destruction here pictured was accomplished in the course of a few days. Even the hardest rock coasts must suffer when subjected to such an attack for countless millenniums.

FIGURE 3. House on New Jersey coast protected by seawall and outlying row of pilings.

FIGURE 4. Same house as Figure 3, with seawall broken and corner of house partly undermined.

FIGURE 5. The house shown in Figures 3 and 4 is here almost completely undermined by the waves.

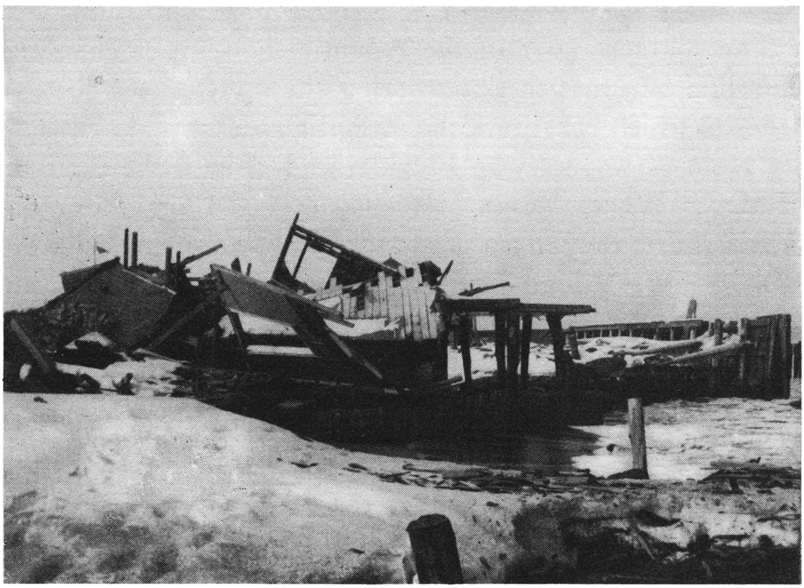

FIGURE 6. Final destruction of house (see Figures 3-5) by wave attack.

CLASSES OF SHORELINES

With this brief introductory word about the force which is chiefly responsible for the modelling of shorelines, let us now consider the two main types of shorelines upon which the waves execute their work. If a land mass is elevated, so that the smooth sea-bottom deposits are brought up to form a coastal plain, the surface of the sea coming to rest against the smooth plain will give a fairly straight or simple shoreline, with shallow water for a long distance offshore, and a gently rising plain landward. Thus we have the class of *shorelines of emergence.* On the other hand, if a dissected land mass sinks, the sea surface coming to rest against the irregular hills and reaching far up the branching valleys will give a shoreline of great complexity, marked by numerous islands, peninsulas, and branching bays. Thus are produced what have been called *shorelines of submergence.*

SHORELINE OF EMERGENCE

The southern part of the Atlantic shoreline is chiefly a shoreline of emergence, bordering the uplifted sea-bottom deposits which constitute the Atlantic coastal plain extending from New Jersey to Florida, and around the Gulf to Mexico. Where waves first encounter shallow water off such a shore, they often erode the sea-bottom and build an offshore bar. Along most of the coast of New Jersey an offshore bar is developed, with a lagoon back of it but little filled with marsh at the north, almost wholly filled toward the south. The transition from upland to salt marsh (Fig. 7) is so gradual, so imperceptible indeed, that it would be almost impossible to draw the boundary between the kingdom of fresh water on the one hand, and the kingdom of salt water on the other, did not trees often mark the one, and salt marsh grasses the other. At the extreme north the sea

FIGURE 7. Transition zone between salt marsh and fresh water vegetation, inner border of New Jersey coastal marshes.

has driven the offshore bar back to the mainland, and the waves are actually cutting into the edge of the land.

In South Carolina and Georgia the coastal plain slopes down into the sea without any offshore bar. The surface topography of the plain is very gently undulating, and as a result along the sea border the gentle rises form islands, while the depressions between give tidal channels. Thus we have the well known "sea-island" topography (Fig. 18).

In Florida we again encounter an offshore bar which changes southward to a line of coral reefs or "Keys." Here the growth of palms in sand covering the hard coral rock (Fig. 8) gives a special charm to the shore scenery, which seems more like that of some island in the South Seas than a part of the United States.

SHORELINE OF SUBMERGENCE

In striking contrast with the scenery of the shoreline of emergence bordering the coastal plain, is that characteristic

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of the shoreline of submergence bordering New England and Acadia. Here an irregularly dissected rocky land mass has been partially drowned to give a shoreline of extreme complexity. Rocky headlands project out to sea, and the ocean waters (Fig. 9) set far back into the drowned valleys.

As a rule the hard rocks have not suffered greatly from marine erosion, although slopes which were already steep before the land was submerged have been sharpened by the waves into impressive cliffs. Most often it is very evident that the sea has merely cut a notch at the base of older slopes, from which we infer that the sea has not stood so very long at its present level. In the remarkable region of the Gaspé peninsula (Fig. 10) the waves have carved fantastic shapes out of vertically tilted layers of limestone where the Appalachian Mountains plunge under the sea. Here we find the famous Roche Percé, which seen from the

FIGURE 10. Percé Rock, Quebec, eroded on vertical beds of limestone.

FIGURE 11. Drumlin of unconsolidated glacial till partly cut away by waves. Winthrop Great Head near Boston.

shore resembles a giant ship coming into the harbor, its prow rising sheer above the water almost three hundred feet. Near its stern the waves have cut an arch which gives the Roche Percé its name. A second arch formerly existed, but its roof caved in many years ago, so that today the seaward end of the giant rock forms a "stack" or "chimney."

Where the headlands (Fig. 11) are composed of unconsolidated glacial debris the waves have cut them back many hundreds of feet, developing sea cliffs of some magnitude and building beaches and bars of the transported materials. Plains of loose glacial sand are cut back even more rapidly, and on Cape Cod, Massachusetts, it has been estimated that a sand-plain of this type has lost about two miles of its seaward border under the attack of the waves.

All along our northeastern coast the material eroded by the waves is built into a great variety of beaches and bars which themselves are often picturesque elements of the shoreline scenery. The material of such beaches and bars consists mainly of sand, gravel, or wave-rounded cobblestones (Fig. 12), which are often washed by waves clear over the beach and deposited on the salt marsh behind. But occasionally, as in places on the Maine coast, an entire beach may consist of giant blocks of granite, plucked from the solid ledge and hurled upon the shore by mighty storm waves (Fig. 13).

Back of the beaches salt marshes frequently occupy the drowned valleys, and add their peculiar element to the landscape. There is something very appealing in these remarkably level stretches of open meadow, separated from the sea by a narrow bar upon which the houses of fisher folk or summer visitors are crowded closely together. Through the salt meadows wind the tidal channels, by which the flowing and ebbing sea holds the territory within the domain of salt water.

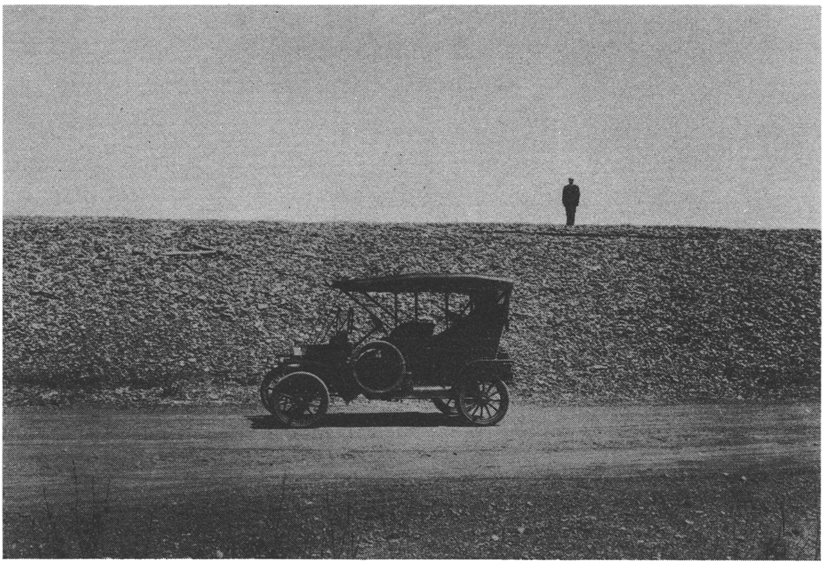

FIGURE 12. A cobblestone beach heaped up by the waves near Rye, New Hampshire.

One element in the shoreline scenery of the Atlantic coast deserves a special word. This is the fjord topography, very rare in the United States, which is the central attraction of Mount Desert Island on the coast of Maine. When the glaciers moved southward across New England they encountered on this island a serious obstacle formed by an east-west range of granite mountains. Striking against the northern side of this barrier, the ice rose higher and higher, until it poured across the lower divides as a series of ice tongues. Each ice tongue ground down the divide to a low level, giving to it the curved profile peculiar to glacial channels. Occasionally this symmetrical curve is exhibited with the clearness of a diagram, and leaves no doubt that here the ice materially modified the earlier topography. Some of the notches were cut so low that the sea has invaded them, giving what may truly be called a fjord topography

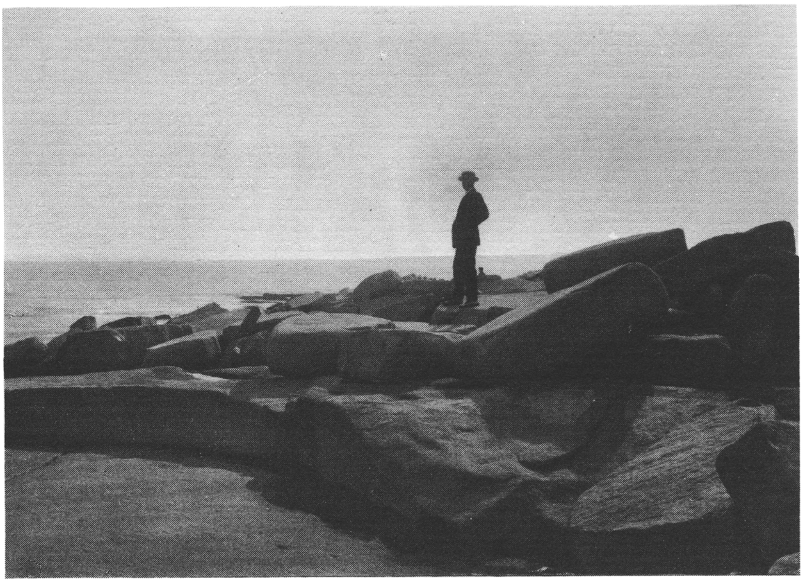

FIGURE 13. A "beach" composed of giant blocks of granite plucked from ledges of the Maine coast and heaped upon the shore by storm waves.

(see frontispiece). The term fjord is often erroneously applied to all the drowned valleys of the Maine coast; but if by a fjord we mean a submerged glacial trough, like those of Norway, then only on Mount Desert Island can Maine boast that it possesses true fjord scenery.

THE PROBLEM OF COASTAL SUBSIDENCE

We have noted the striking contrast between the scenery of the shoreline of emergence bordering the coastal plain of the southeastern United States, and that of the shoreline of submergence bordering New England and eastern Canada. Without further preliminaries let us turn at once to a consideration of the significance of these shores as related to the question of modern coastal subsidence. This question has claimed the attention of many American geologists, and even appealed to the popular imagination as reflected in articles in the daily press. Some years ago, when the venerable Professor Newberry, then professor of geology at Columbia University, had published evidence indicating a gradual sinking of our Atlantic coast at the rate of one or two feet per century, one of the New York newspapers published a cartoon showing a wide waste of waters with only the roof of one of the Columbia University buildings projecting above the flood. To the spire at the top of the nearly submerged building Dr. Newberry was shown clinging with one hand, while in the other he waved a Columbia flag as he shouted proudly: "I told you so! I told you so!" It is to this fascinating problem of recent coastal subsidence that we now give our attention.

ARGUMENTS FAVORING RECENT SUBSIDENCE

We have already seen that the waves cut into our shores, and undermine and destroy our houses with extraordinary vigor (Figs. 3–6). On the coast of Massachusetts a lighthouse on Cape Cod has repeatedly been moved back, because the relentless attack of the waves cuts away the coast at the rate of more than three feet per year. On the coast of Cape Breton Island weak sandstones are similarly being eroded with great rapidity, for photographs taken only a few years ago show that then the solid land extended out to where we now find only an isolated pinnacle of rock in the sea. The roads along this latter coast have been eaten into and undermined by the sea, so that old roads end abruptly at the top of high cliffs, and have been replaced by new roads farther back. Near the town of Sydney a road following the coast has repeatedly been moved back, as earlier roads were destroyed by the advancing waves.

Perhaps a little consideration will convince you that these phenomena are in themselves proofs of a gradual sinking of the land. If the coast stands still a long time, the waves weaken in their attack as they cut farther and farther inland. This is because the waves have to cross the shallow submarine platform produced when they planed away former extensions of the land. Friction on this platform weakens wave action. Had not the land continued to sink, the waves would therefore today be powerless to accomplish any rapid erosion. Thus able geologists have reasoned that only where there is progressive subsidence, constantly lowering the wave-cut platform to give deeper water close to the land, can vigorous wave action continue to destroy the coast in the manner shown in the cases we have described.

Equally convincing is the evidence furnished by submerged stumps of forest trees. The view represented in Figure 14 was taken thirty-five feet below high tide level in the Bay of Fundy, where the range of tides is great. Yet one sees the remains of a dense forest, stumps of pine trees, birches, and other upland trees, deep-rooted in the soil in their original positions. Certainly the trees grew precisely where we see them; and equally certainly when they so grew they were above sea-level. Today the rising tide buries them under thirty-five to forty feet of salt water twice each day. One could not have clearer evidence of a sinking of the land, for the stumps are fresh, and the roots of ferns are still found in place about them.

All along the Atlantic coast the process of transforming upland trees into submerged stumps may be observed in scores of places. On the coast of Georgia (Fig. 15), for example, as indeed in many other places, the salt marsh is invading the forest; some of the trees are just dying, others are dead, and still others are reduced to stumps in the marsh by the decay and fall of the dead trunks. Obviously the process of submergence is still going on at a rate which must be comparatively rapid.

A curious bit of evidence from the region of Albemarle

FIGURE 14. Submerged forest near Fort Lawrence at head of the Bay of Fundy.

FIGURE 15. Tidal marshes encroaching upon forest and killing trees. Border of the Little Ogeechee River, Georgia.

and Pamlico Sounds of North Carolina points to the same conclusion. These sounds are at sea-level, being in fact bays of the ocean shut off by the development of the offshore bars we have earlier described; but they are in part fresh water lagoons, due to the influx of large quantities of fresh water. In their margins groves of cypress trees (Fig. 16) are found growing where the water is six or eight feet deep. The trees are alive, because the water is not saline; but most assuredly the trees never began growing under water. Hence it has been concluded that the land must have been at least six or eight feet higher when the trees began to grow, and must have subsided to the present level during the lifetime of the trees.

In our salt marshes are occasionally found small round islands (Fig. 17), sometimes covered with large trees. Examination shows that the islands are really Indian shell

FIGURE 16. Cypress trees on the embayed coast of North Carolina, near Elizabeth City.

FIGURE 17. Island in salt marsh near Tuckerton, New Jersey, formed by Indian shell heap.

heaps, the remains of countless Indian feasts; for the shells are interstratified with the charred remains of camp-fires and with Indian relics of various kinds. The important fact for us is that the bottoms of the shell heaps are a number of feet below the level of the marsh, which itself marks approximately the level of ordinary high tides. Surely the Indians did not select for their camp-fires and feasts places from which they would be driven twice daily by the sea. It has therefore been inferred that the shell heaps were built above the tide level, and that since the time of the Indians a gradual sinking of the land has carried the former camp sites below tide level, the marshes meanwhile building up, as is their habit, to the new level of the sea.

There is a quantity of evidence which has been used to fix the rate of land subsidence with a reasonable degree of accuracy. In these same marshes are found tidal mills, the wheels of which were adjusted to the proper level to have them turned most effectively by the tidal currents flowing in and out of the channels through the marshes. From fifty to a hundred years after the mills were built it was found that they, with their wheels, were from one to two feet lower, so that they no longer worked properly. Low islands of solid upland in the marsh, which in the earlier days of New Jersey contained a certain known number of acres as shown in the recorded deeds of farms and other property, are now much smaller, or have entirely disappeared under the salt marsh, where their presence can be verified by sounding through the soft marsh deposits with an iron rod. The thickness of marsh over the buried upland indicates a subsidence of about two feet per century. The dyked and reclaimed marshes of the Bay of Fundy region, and those along the shores of Massachusetts, New Jersey, Georgia, and other states, are lower than the unreclaimed salt marsh, showing that since the dykes shut off the reclaimed lands, they have been carried downward at the rate of one or two feet per century. In Boston Harbor a bench mark cut on the stone wall of a dry dock in the U. S. Navy Yard to record mean sea-level when the dock was built, was found to be seventy-five hundredths of a foot below mean sea-level when carefully studied seventy-five years later, thus suggesting a subsidence at the rate of one foot per century for that area.

I cannot attempt to reproduce here all of the voluminous evidence tending toward the same conclusion, namely that the eastern coast of North America is sinking at the rate of one or two feet per century. As has been noted, the evidence is not only to be found in the character of the scenic features along the coast, but the artificial records of man and his activities furnish abundant corroborative data. If all the evidences of subsidence could be given, the case would seem even more conclusive; but I have said enough to reveal the great variety of the kinds of evidence, and to suggest how strong must be the whole chain of evidence when completed.

ANALYSIS OF FOREGOING ARGUMENTS

If I have succeeded in making a convincing case in favor of the theory of recent progressive coastal subsidence, it is a measure of my success in presenting with fairness the arguments of many of my colleagues who believe that such a subsidence is taking place. Now I must make a confession. I have tried to act the part of a good lawyer; and like certain of my honored brethren of the legal profession, I have done my best to make the worse appear the better cause. All of the facts I have stated correctly, as becomes both good lawyers and good scientists. But all of the arguments and conclusions derived from those facts I believe to be wholly erroneous. They are the arguments and conclusions which one will find abundantly set forth in geological and geographical literature. Yet I shall now attempt to show that all of the observed facts are really in accord with the conception of a stable coast, and that other facts prove such stability has long been maintained.

The facts of rapid erosion of the coast, with consequent destruction of buildings (Figs. 3–6) and roads, are fully attested; but the argument that the rate of erosion observed must depend on subsidence seems to be fallacious. If we project the upland slopes out to the sea, we find that a strip of land varying from a few hundred feet at most in hard rocks, to as much as a mile or two in soft material, has been cut away. There is no doubt that when the wave cutting began the rate was very much faster than now. Then the rate may have been ten, twenty, or more feet per year under favorable conditions; and the comparatively low rate of a few inches or two or three feet per year now, represents the extent of the weakening of the waves as they have to run farther and farther across the shallow platform they themselves have carved. But there is no evidence to indicate that the present rate is not just what it should be on a stable coast into which the waves have cut the distances indicated. In other words the argument in favor of subsidence is based, not on the *fact* that the waves cut two or three feet into the land each year, but on the unsupported *assumption* that this rate is too great for a stable coast. I think the evidence presented later will convince you that this assumption is erroneous.

The beautiful example of submerged stumps seen far below tide level at the head of the Bay of Fundy (Fig. 14), is quite unrelated to the problem of *modern* coastal subsidence. The stumps are part of an upland forest which has been traced down under the marsh deposits of this region by numerous excavations for canals and wells. The marshes extend miles inland as narrow strips between forested ridges, and if one were to remove these marsh deposits one would find everywhere, at the bottom, the stumps of a forest buried thousands of years ago by a much earlier subsidence, but kept fresh and sound because sealed from the air under a compact cover of marine clay many feet thick. The deposition of this clay required a long time, and one who studies the region can have no doubt that the burial of the trees occurred long ago. Recently the waves and tides have washed away the clay along the coast at the point in question, revealing the ancient stumps as an apparently recent phenomenon, thus giving a fictitious appearance of recent subsidence.

But there are other ways in which submerged stumps are formed. Where trees grow on a peat bog, and the sea cuts laterally, but without change of level, into the bog, the draining and leaching of the seaward edge of the bog causes it to settle. This carries the trees down below high tide level, resulting in their death and the formation of stumps submerged at high tide, to give again a fictitious appearance of recent coastal subsidence. Trees growing along sandy shores (Fig. 18) are undermined by the waves and let down into the water, a phenomenon frequently witnessed among the Sea Islands of Georgia. There the trees die, leaving submerged stumps which really indicate no change in the relative level of land and sea. Figure 19, representing a view on the Georgia coast, shows in a beautiful manner how the species of pine having a deep-penetrating central tap root may leave "submerged stumps" without any real subsidence of the land. At the right is observed a pine in healthy condition growing on the shore and sending its tap root deep below high tide level. As the ground water drains outward from

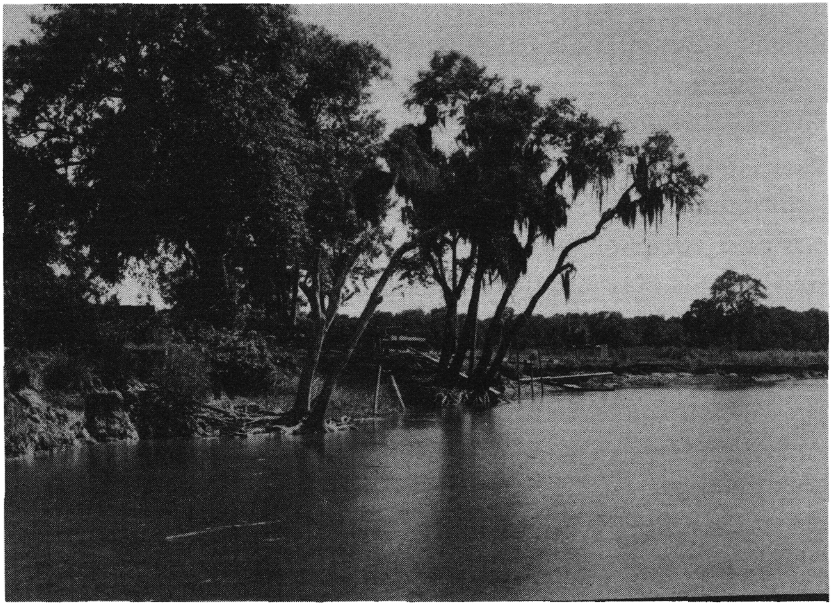

FIGURE 18. Trees being undermined by wave action and killed by salt water, in the Sea Islands of Georgia.

the land to the sea, the root is never damaged by salt water. Next to the left is a large pine, dying because the earth has been eroded from around its roots, which are then reached by the salt water. Farther out are two more trees, further along in the stage of decay, but with the horizontal roots showing that the land level at which they grew has not changed; it is still above tide. Next only the stump is left, while in the foreground two examples show that when the stump and lateral roots have decayed, the central tap root will remain to give what are popularly mistaken for submerged stumps proving recent coastal subsidence. One could scarcely imagine a more beautiful case in which Nature demonstrates in a single view every stage in the formation of one of the fictitious evidences of changes of level.

For the trees observed dying in marshes along the coast

FIGURE 19. Successive stages in the formation of "submerged stumps" where waves undermine trees without change of level. North end of St. Catherine's Island, Georgia.

(Fig. 15) there is another, and even more interesting, explanation. This type of evidence is almost always observed in bays, and while present in some bays is wholly absent from others with similar shores immediately adjacent. Such a relation in itself should arouse one's suspicion as to the correctness of interpreting the death of the tree as due to subsidence; for subsidence should affect the outer coast as well as the bays, and should involve all bays in a given locality if it involves any. I therefore sought an explanation for this peculiar phenomenon, and discovered one which I believe is of the very highest importance in explaining a large proportion of the fictitious evidences of subsidence along our coast.

If we imagine a broad bay separated from the sea by a bar, and imagine further that somewhere in this bar a narrow tidal channel permits the sea to flow in and out of the bay, we shall have all the elements necessary for our explanation. For it is obvious that when the tide rises in the open sea, it will flow through the narrow channel in the bar and spread over the broad surface of the inner bay so slowly that in the bay the tide will rise only a short distance before falling of the ocean tide to low-water level will start the bay waters running out again. Thus the tide in the bay never rises above the level AB (Fig. 20); and naturally within the bay the trees grow down to the level of this lower high tide level, or down to A.

Now imagine that some great storm breaks a broader opening through the bar. The ocean tides may now enter freely, and high tides in the bay rise as high as they do in the open sea, or to the level CD, killing the trees between A and C. Or if the storm completely removes the bar, and the bay is funnel-shaped, the compression of the tidal wave running inward toward the narrowing bayhead may cause

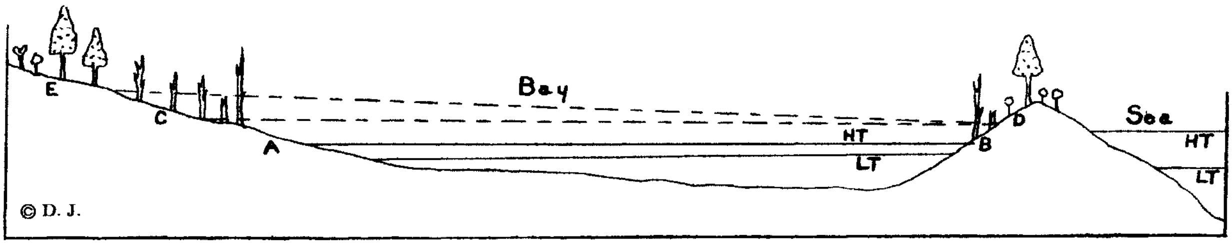

FIGURE 20. Diagram showing fictitious subsidence of the coast; as long as the barrier beach (D) nearly closes the mouth of the bay, high tide (HT) in the bay is lower than high tide in the open sea; trees grow down to this lower level (AB) along the shores of the bay; when the barrier beach is broken through or removed, high tide in the bay rises as high (CD) as the open sea, and all the trees between the levels AB and CD are killed by the salt water; if the bay narrows going inland, the tide is forced to rise even above the level it attains in the open sea, or to the position ED, and at the head of the bay all the trees between A and E are killed; in addition to these submerged forests, other fictitious indications of subsidence are thus produced.

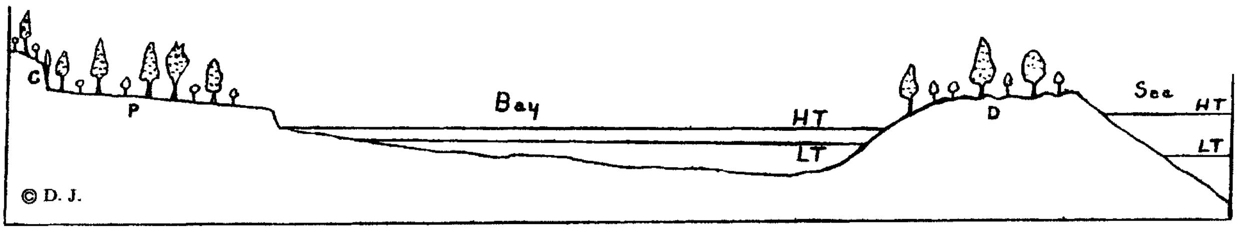

FIGURE 21. Diagram showing fictitious elevation of the coast; before the barrier beach (D) was constructed, the tide in the bay rose as high as in the open sea, and the cliff (C) and platform (P) were carved by the waves; since the building of the barrier beach, high tide (HT) in the bay is lower than in the ocean, the cliff and platform are no longer reached by the waves, and appear to represent an "elevated shore line"; the uniform altitude of the beach ridges on the barrier beach shows that the relative level of land and sea have long remained constant.

the water there to rise even higher, to the level E, when all the trees between A and E will be killed. As the breaking of the bar, or the mere widening of the channel across it, will occur in some bays, and not in others, the phenomenon of dying forests should be discovered on the shores of some bays and not on others, which we have seen is actually the case.

A good opportunity to test this theory of tidal fluctuations presents itself near Scituate on the coast of Massachusetts. Prior to 1898 the mouth of the North River bay was nearly closed by a bar, and the range of the tides in the bay was small. But in that year a great storm broke a wide opening across the bar, permitting the tides in the bay to rise nearly two feet higher than formerly. Immediately the trees (Fig. 22) about the shores of the bay began to die, and today we have as remarkable an illustration of a

FIGURE 22. Shore of North River embayment, near Scituate, Massachusetts, showing trees killed by local rise of tide due to change in form of the shoreline.

FIGURE 23. Abandoned marine cliff west of Beaufort, North Carolina, covered with dense vegetation because protective bar and lowered high-tide level prevent effective wave erosion.

dead forest with the salt marsh invading the trees as one could wish to see. In the bay next south are stumps buried in the marsh, known to represent trees killed in 1811 when fishermen made an artificial cut through the bar blocking that bay, with a resulting rise in the high tide level. Yet both the dead trees near Scituate, and the stumps in the adjacent bay, have been cited as proof of a gradual sinking of the coast.

One may say: "If such tidal changes cause phenomena of submergence, opposite changes should cause fictitious evidences of emergence (Fig. 21). For if the tides of an open bay originally rose as high as tides in the ocean, carving a cliff (C) and platform (P) ; and later a bar formed across the bay with a tidal inlet so small that thereafter the range of tides in the bay was restricted and salt water never reached

FIGURE 24. Abandoned marine cliff and platform between Miami and Cocoanut Grove, Florida, covered with vegetation because protective bar and lowered high-tide level have stopped wave erosion.

the platform or cliff, trees should cover the latter and give the appearance of an elevated shoreline due to uplift of the land." Such tree-covered cliffs and platforms do exist along the coast, examples being found on the shores of bays in New Jersey, North Carolina (Fig. 23), Florida (Fig. 24), and in a number of other localities. In all of these cases a bar shuts out the sea effectively, the tidal range is small, storm waves no longer reach the cliffs, and there can be little doubt that the apparent evidence of uplift is fictitious. This emphasizes the importance of tidal fluctuations as causes of fictitious indications of subsidence; and I believe that the major portion of the remaining indications of subsidence earlier referred to, such as mill-wheels refusing to work, low islands covered by rising salt marsh, bench marks apparently lower than formerly, and many others which might be cited did time permit, are really the product of local tide changes unrelated to any general change in the level of land and sea.

But not all fictitious indications of subsidence are thus to be explained. The cypress trees (Fig. 16) in the sounds of the Carolina coast grew on a peat bog, and waves washing away the soft peat left the trees standing supported by their spreading roots. The greatly thickened boles of the trees, which form just above the ground level, show that where now is open water there must formerly have been soil with its level the same as in the adjacent peat bogs. Had the land sunk six or eight feet, the thick boles would be far down under water by this time, and only the narrow upper trunks would show above sea-level.

Indian shell heaps (Fig. 17) were apparently built along tidal channels where the canoes could land; the constant mi-

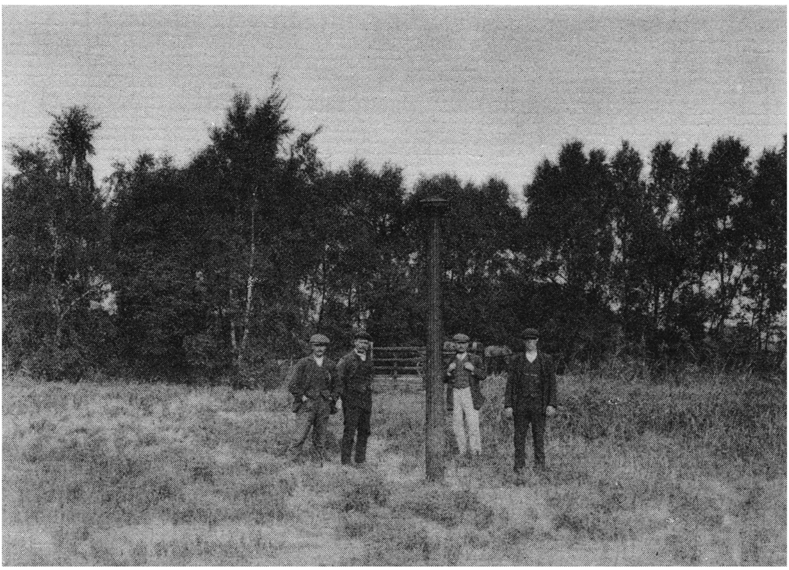

FIGURE 25. Iron post with cap on top marking level of the ground in 1848, before settling due to draining reduced surface to its present level. English fenland near Peterborough.

gration of these channels undermines the deposit on one side, and lets it down below marsh level where deposition on the opposite side soon covers it. So the finding of parts of such shell heaps below marsh level should not be mistaken for an evidence of subsidence. Furthermore, the heap as a whole, especially when large trees have grown upon it, has enormous weight, and the entire mass presses down into the soft marsh deposit until the bottom is a number of feet below marsh level.

Dyked marsh lands always dry out and settle when drained, as experience in Holland, the Fens of England, and other parts of the world has abundantly proven. To measure the amount of settling in the English Fenlands iron posts are driven through the marsh deposits and into firm clay beneath, before the reclamation works are begun. In one case which I examined the surface of the ground has sunk thirteen feet since the marshland was drained in 1848 (Fig. 25).

Comparative studies of mean sea-level based on very accurate tidal records running over a period of thirty to forty years, seem to suggest a progressive subsidence of the land in some places, a progressive rise in others. But we must remember: first, that these records cover a very brief period of time; second, that they show a quantitative change very much smaller than the supposed one or two feet per century; and third, that they may be due wholly to local variations in mean sea-level due to changes in the form of the shore, the depths of tidal channels, the direction and velocities of tidal currents, resulting from both natural and artificial causes. Thus in turn might we show the fallacy of every argument advanced in favor of a recent subsidence of the Atlantic coast. After a long and critical study of this fascinating problem, I have been unable to find any reliable evidence of a long-continued progressive subsidence of the coast within historic time.

EVIDENCES OF COASTAL STABILITY

Back of the present offshore bar there is sometimes found an earlier bar (Fig. 26) ; and the level of the two is so nearly the same that no marked change in the level of the land can have occurred in the interval between the formation of the earlier and later ridges. Similarly, back of the present shore there are ancient abandoned cliffs in front of which in certain cases two or three successive shore lines have since developed, each involving a bar that must have required a long time for its growth. The base of such abandoned cliffs is still slightly above sea-level, proving that no appreciable subsidence has occurred during the period in which the different shorelines were developing. On the coast of Florida,

FIGURE 26. Salt marsh back of offshore bar near Atlantic City, New Jersey, showing (in middle distance) an earlier bar of same type.

Cape Canaveral (Fig. 27) shows a series of not less than twenty-six successive shorelines, formed one after the other, to give a wave-built plain five miles in breadth. In Figure 27 one may count a number of these shorelines, in the form of successive ridges and swales, curving to form the point of the Cape at different periods. According to our best information concerning the rate at which shore forms of this type are built, it probably required several thousand years for the waves to construct so extensive a series of ridges; yet the oldest and youngest have approximately the same level. Near Boston (Fig. 28) a number of oval hills composed of glacial debris, called drumlins, have been more or less completely destroyed by the waves. With the eroded debris the waves have built a succession of curving beach ridges. The oldest of these beach ridges differs so little in height from the latest that no marked progressive change in the level of land or sea can have occurred during the time

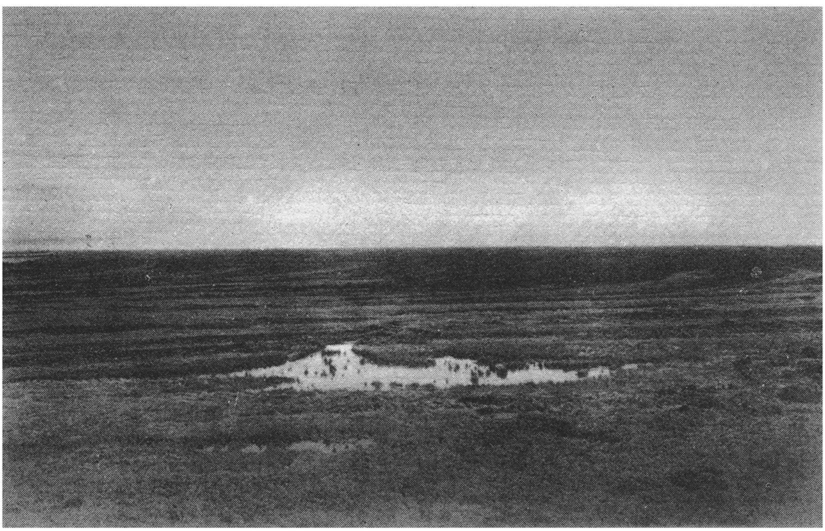

FIGURE 27. Beach plain of Cape Canaveral, Florida, showing successive ridges and swales marking former shorelines of the Cape.

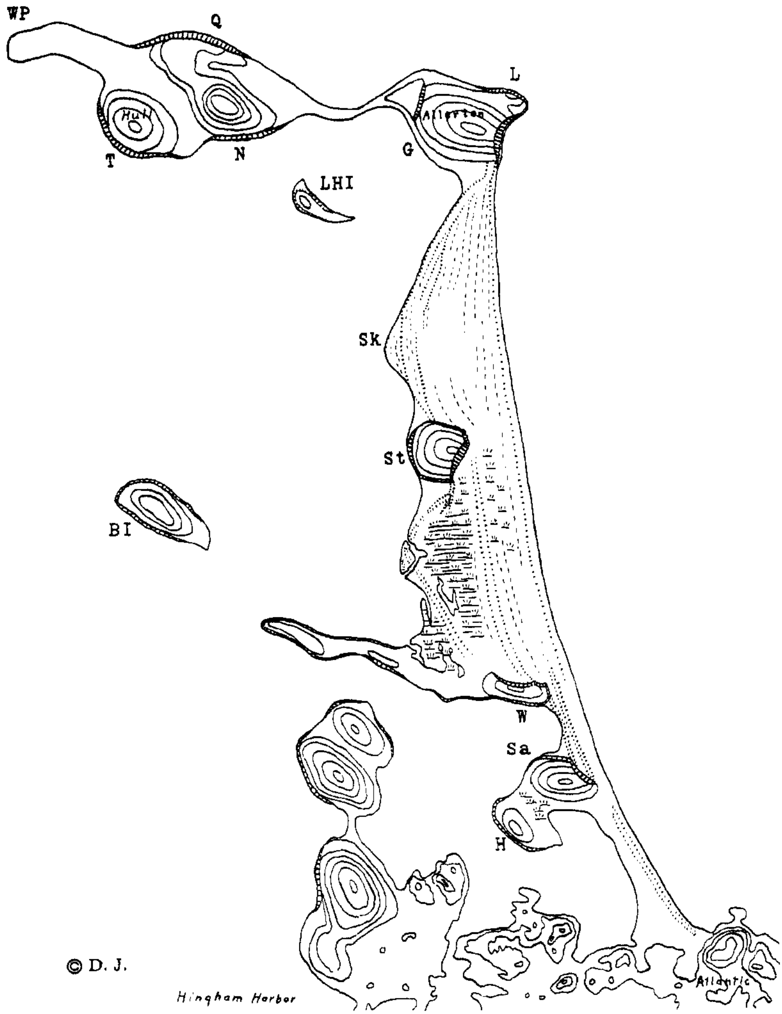

FIGURE 28. Nantasket Beach near Boston, composed of former islands partially eroded by waves and tied together by wave-built beach ridges and bars.

of their building. The ridges were built as the hills were eroded; and since we know the rate of wave erosion on the hills, it is possible to say with some certainty that the building of the ridges must have required one or two thousand years, and possibly more. Thus we secure further physiographic evidence of a long-continued stability of the land. In his classic essay on the "Outline of Cape Cod" Professor Davis has shown that since an ancient abandoned cliff on the Cape was formed, several thousand years must have elapsed. I find that the base of this cliff, long protected from the sea by a marsh and offshore bar, has the same position with respect to sea-level as the bases of modern cliffs along the present shore. Here again we find confirmation of the conclusion that the level of land and sea has remained essentially unchanged for a very long period of time.

The record of precise measurements does not extend over a very long period, but it is sufficiently extended to reveal a subsidence of one or two feet per century if such exists. I have approached this part of the problem from two directions. In the first place, since it is probable that a land subsidence so marked as that supposed to occur on our coast would not involve the whole country equally, but would be accompanied by warping or differential movements of the crust, I have sought to learn whether or not successive surveys on our coast reveal any clear evidence of warping. For this purpose I asked the Director of the Geological Survey of New Jersey to re-survey a triangle in that state which had previously been surveyed a quarter of a century earlier. The results of this investigation showed that over this large area the greatest apparent difference in the relative positions of the three points is only two hundredths of a foot, or less than the probable error in the original survey. Similarly, precise level surveys by Koop have shown that the relative position of two survey bench marks, located about thirty-three miles apart in northern New Jersey and southern New York, has apparently changed but slightly over one millimeter in a quarter of a century. In this case, as in the one first mentioned, the apparent change is less than the probable error of the older survey, which was certainly less exact than the modern measurements. Hence we may say that so far as evidence of warping is concerned, it is wholly negative. If there has been any appreciable change of level in the last quarter century, the whole land must have subsided equally, or the sea-level must have risen.

To test the last possibilities, I have compared the determination of mean sea-level as made in the vicinity of New York for two epochs averaging about a quarter of a century apart. If the land sank or the sea-level rose at the rate of two feet per century during that period, there should be a difference of one hundred and forty-six millimeters in the two determinations. As a matter of fact, there is only a difference of four, or less than half the probable error in determining mean sea-level itself. In other words, there must have been approximate, if not absolute, stability of land and sea during the twenty-five-year interval in question. Finally, a similar comparison between the position of a survey bench mark referred to mean sea-level by two surveys twenty-four years apart, shows that throughout that interval the bench mark remained almost exactly the same distance above sea-level. The two surveys showed an apparent difference of only one half of one millimeter, whereas there should have been a difference of one hundred and forty-six millimeters had the land subsided or the sea-level risen at the supposed rate of two feet per century.

We may safely conclude, therefore, that the evidences of marked recent subsidence are fictitious and not real, and that the land has remained at least approximately stable for several thousand years. Neither New York nor the buildings of Columbia University seem in imminent danger of being submerged. But even if this dramatic element in our coastal history be lacking, the scenery of the coast, and the lessons it teaches, are none the less interesting.

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